SONY BASIC VIDEO RECORDING COURSE

BOOKLET #8

COLOR SIGNAL PROCESSING

SONY®

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Introduction

In this booklet we will reveiw some basic aspects of the NTSC color system that are important to an understanding of VTR color processing. We will then study the basic test signal, 75% color bars, and look at the troubleshooting aspects of color processing.

1. REVIEW OF COLOR CONCEPTS IMPORTANT TO VTRs

The VTR does not demodulate, or take-apart, the color signal to produce its original modulating components. In the direct-recording method employed in broadcast quality VTRs the entire composite signal, color and all, is handled much like the luminance signal, in the same manner studied in the previous lesson. In industrial and home VTRs the multiplexed color signal is simply extracted and shifted to a new center frequency for recording purposes. In playback the color signal is shifted back to its original center frequency at 3.58 MHz. We need to review, here, the character of the multiplexed signal, how it is put together and how the VTR handles or mishandles it.

Basic Concepts. All color TV systems in use today are based on visual reproduction in terms of three color components—red, green and blue. A very high quality color system can be assembled as shown in Fig. 1. Here three separate pick-up tubes, with filters to make them sensitive in the red, green, and blue parts of the visual spectrum develop separate R, G and B signals. These are routed directly to the RGB drive elements of a tri-color picture tube. This system, while producing a better picture than human vision actually needs, is too costly in terms of spectrum space. Transmission of such a signal requires three cables or three TV transmission channels.

Fortunately, the limitations of human vision provide the key to bandwidth reduction. We cannot discern color in very small areas of the picture. Think of your own daily experience. If you look at a bridge, derrick, or sailboat from a distance you might see the cables, ropes, pennants, etc. quite clearly but not be able to determine hue. It might come as a surprise that the anchor rope of a boat is actually gold in color, but from a distance it simply looked black or gray against the background.

In terms of the video bandwidth needed to match visual acuity, and based on a normal viewer placed at a distance of eight times the picture height from the TV screen, we need about 4 MHz for variations in brightness alone (black and white and shades of gray). We need about 600 kHz for all colors. We can't really determine all colors in smaller areas of the picture. Finally, we can discern orange and cyan in slightly smaller areas, representing picture detail, or perhaps a pattern of vertical lines, up to about 1.2 MHz.

Compatibility. One of the factors facing the developers of the NTSC system was compatibility. That is, color transmissions must produce a normal black-and-white picture on the TV sets then in existence. (The field-sequential system adopted by the FCC in 1951 was not compatible because it used a different field and line rate than the standard 60 Hz, 15, 750 Hz rates.) Any one of the RGB signals of Fig. 1. would not work. For example, the red signal, if applied to a black-and-white monitor would show a girl's lips as white, her green hair ribbon and her blue eyes as black. To produce monochrome picture with the expected gradation from white through gray to black, the camera must have a spectral sensitivity that closely matches the spectral sensitivity of human vision. Vidicons made for monochrome cameras are tailored to approximate the response of human vision as closely as the materials used in the target will allow. Fig. 2. shows how human vision sensitivity varies. Note that we are most sensitive to light in the yellow-green part of the spectrum, less sensitive to red and least sensitive to blue.

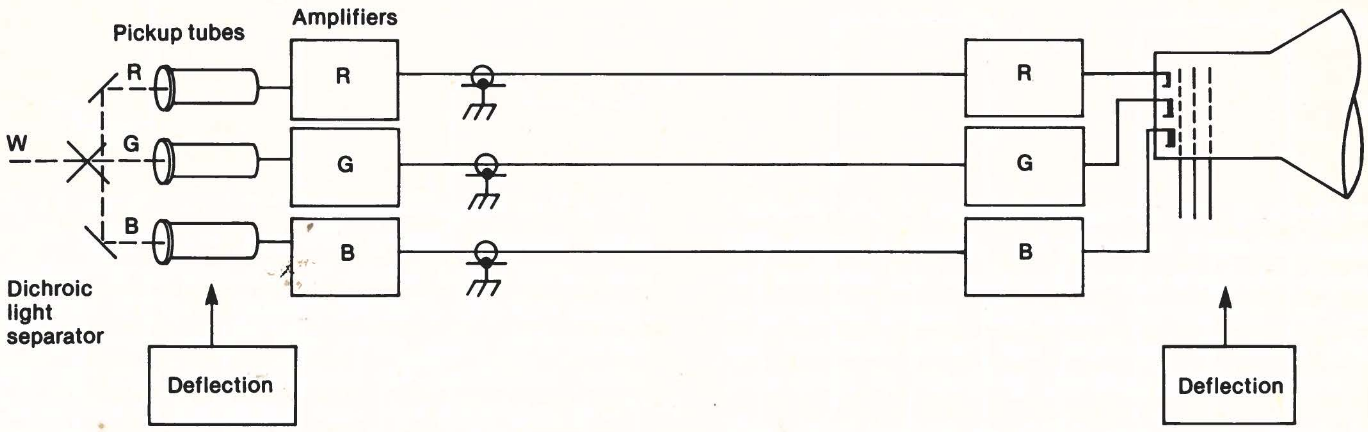


Fig. 1. Elementary color TV system based on red, green, & blue components.

A very close approximation of the visual sensitivity curve can be made by taking the correct values of the RGB signal produced by the pick-up tubes in Fig. 1. Using the primary colors that have become standard, the recipe is 30% of the red signal (R), 59% of the green (G) and 11% of the blue (B). This yields a monochrome signal, called the Y signal, that results in a natural gray scale, approximately the same gray scale that would be produced by a black-and-white camera looking at the same scene. Here's the recipe: $Y = 0.30\,R + 0.59\,G + 0.11\,B$. Note, this is not a formula for white. The mix ratios of red, green and blue to make white are another matter having to do with the efficiency of individual camera tubes or phosphors.

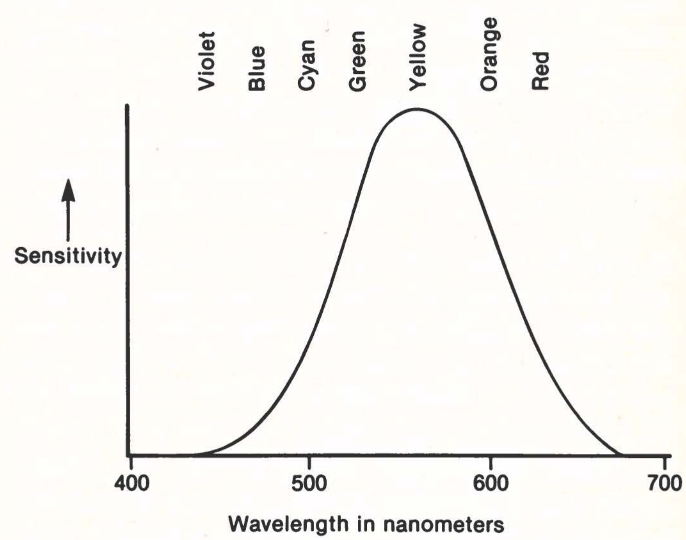


Fig. 2. Human visual spectral response.

The Y signal at full 4.2 MHz bandwidth makes the expected black-and-white picture on a monochrome receiver. What has to be sent to the color receiver, in addition, are the signals that will restore color in terms of R, G and B.

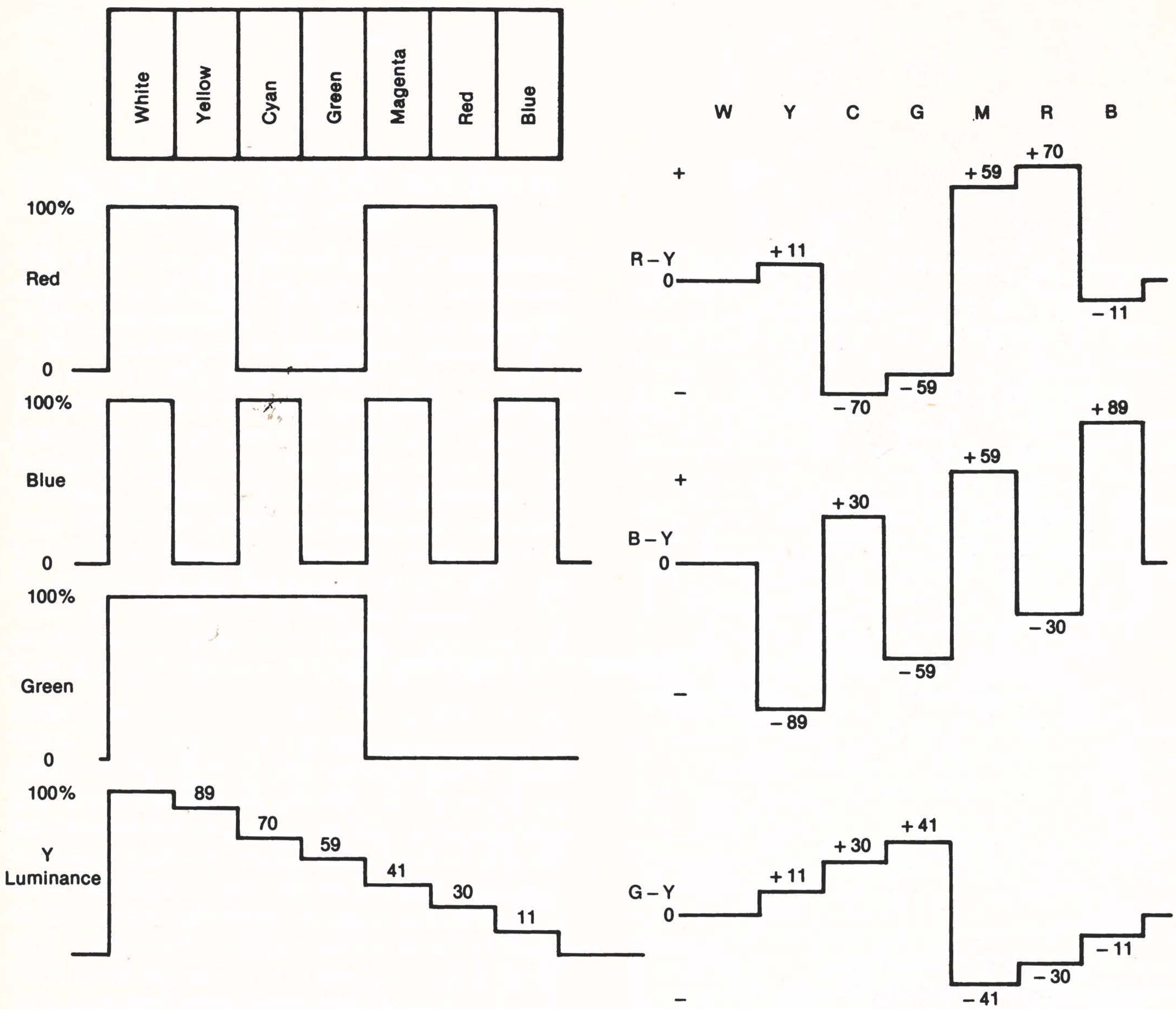


Fig. 3. Y and color-difference signals for 100% fully saturated color bars (setup neglected).

The Color-Difference Signals. The Y signal, called the brightness or *luminance* signal is transmitted for use by color and monochrome sets alike. What the color set needs in addition is the remainder—the difference. For this purpose, Y is subtracted from R, G and B by the simple process of inverting Y and adding it to each of the primary color signals. This yields three signals, R – Y, B – Y, and G – Y. They are carried to the color picture tube by a multiplex process where they are added back to Y. Thus, Y + (R – Y) = R, Y + (G – Y) = G and Y + (B – Y) = B. The color difference signals are called the *chrominance* signals because they carry the information needed to turn the monochrome signal (Y) back into the original red, green and blue components. Fig. 3. shows the construction of the color difference signals by subtracting Y from the fully saturated RGB signals used in the color-bar signal.

But if we think of it, the transmission of Y and 3 color-difference signals would require four cables or channels, whereas only three are needed in Fig. 1. Clearly there is one too many. In fact any one of the three color difference signals can be reclaimed by particular combinations of the other two. For example, G – Y can be made from the addition of 51% of the negative R – Y and 19% of the negative B – Y signal.

Now we have only two color-difference signals to transmit, and the bandwidth required is only about 600 kHz for full-color reproduction. Our next consideration is how to multiplex the transmission of two color-difference signals, occupying a restricted bandwidth within the bandwidth alloted for the full video signal. It is in this approach to multiplexing that the different systems used in the world begin to go separate ways.

But before we look into multiplexing, let's review some basic attributes of the information carried in the color-difference signals.

Hue and Saturation. Visual sensation can be classified into three areas to describe the "color" of an object. These are brightness, hue and saturation. Brightness relates to the total energy, direct or reflected, and is carried in the color signal in terms of the Y signal. Hue refers to the predominant wavelength in the color spectrum. When we refer to objects being green, pink, yellow, etc., we are referring to the hue of the object. The color-difference signals carry hue information. For example, when the color-difference signals of Fig. 3. are added back to the Y signal the green bar goes from 59% back to 100%; red and blue drop to blanking and the bar changes from a medium shade of gray to green. Likewise, during the yellow bar red and green are restored to 100% and blue goes to blanking yielding 100% yellow.

The terms vivid or deep are often used to describe saturation. This refers to spectral purity or freedom from dilution with white. Red becomes pink if there is some dilution with white, if the other two primaries have some output there will be some white (red, green, and blue) but a preponderance of red to make pink. Fully saturated color, 100% saturation, results when there is no white, when one or two of the primaries are absent. Thus a 100% saturated yellow occurs when there is no blue, 100% blue when green and red are absent, and 100% magenta when green is cut off.

Partial saturation of the color bars shown in Fig. 3. would result if the color-difference signal were below the correct amplitude when added back to Y. In that case, for example, the B – Y signal would be less than – 0.89 at the same time that the yellow bar is scanned and would not reduce the B signal to blanking to produce a fully saturated yellow. Thus, saturation relates to the relative amplitude of the chrominance signals.

Note that the amplitude of each of the color-difference signals is zero during the white bar. White or gray represents saturation, all primaries equal, and the chrominance signals are zero at this time.

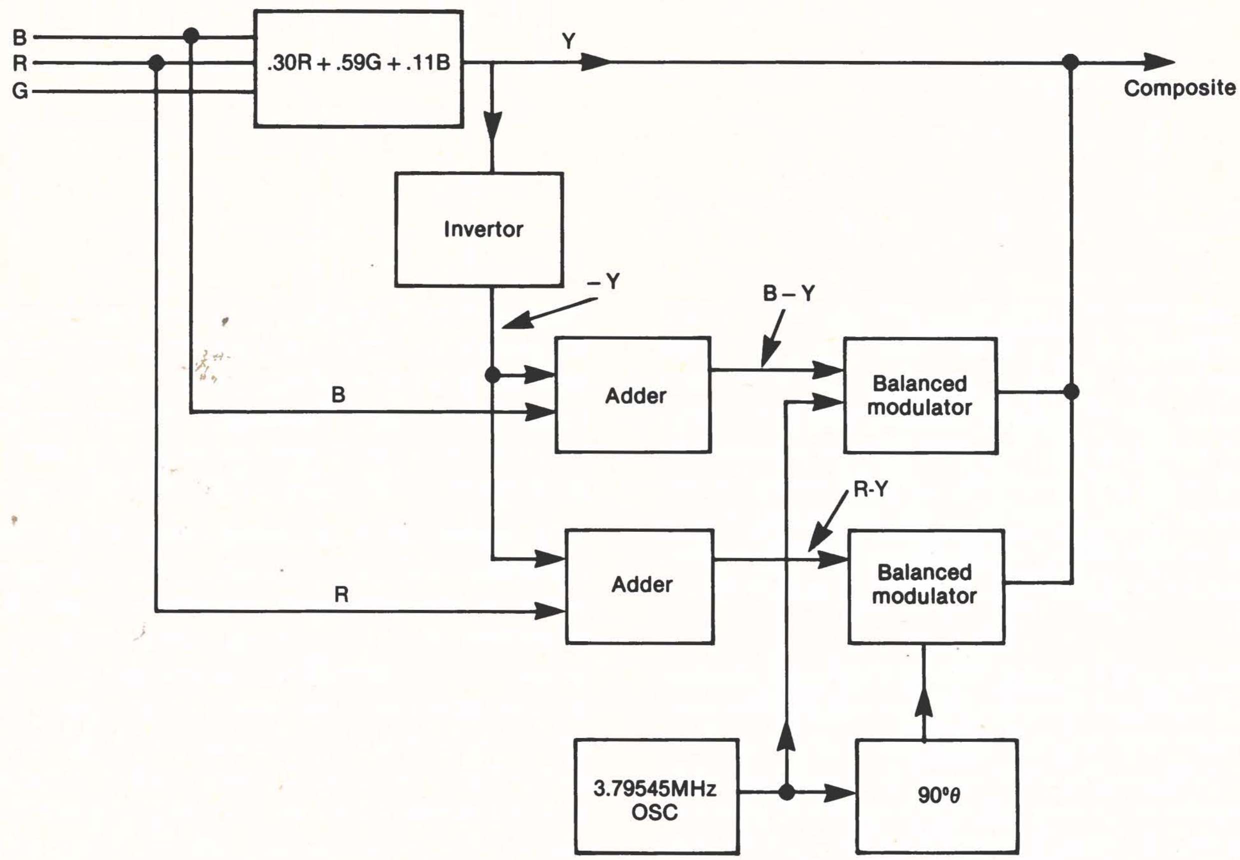


Fig. 4. Basic two-phase amplitude modulator (encoder).

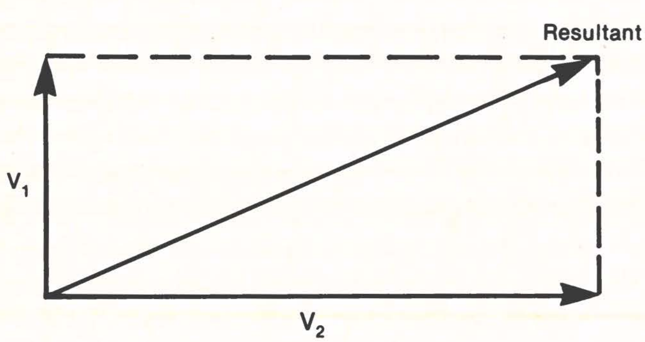


Fig. 5. Vector addition of two signals 90° apart in phase.

Multiplexing. The system chosen in the U.S. to multiplex two of the color-difference signals is *amplitude modulation* on a single subcarrier frequency. Two amplitude modulators are used, each fed with carrier signals that are 90° apart in phase. See Fig. 4. The modulators are special in that they are balanced. This means that they produce no output when the applied color-difference signal is zero. Thus there is no subcarrier output when the camera is scanning white, gray or black.

The outputs of both modulators are added together. When two signals of the same frequency that differ in phase are added together the result is found by adding them vectorially. See Fig. 5. Thus the phase of the resultant is

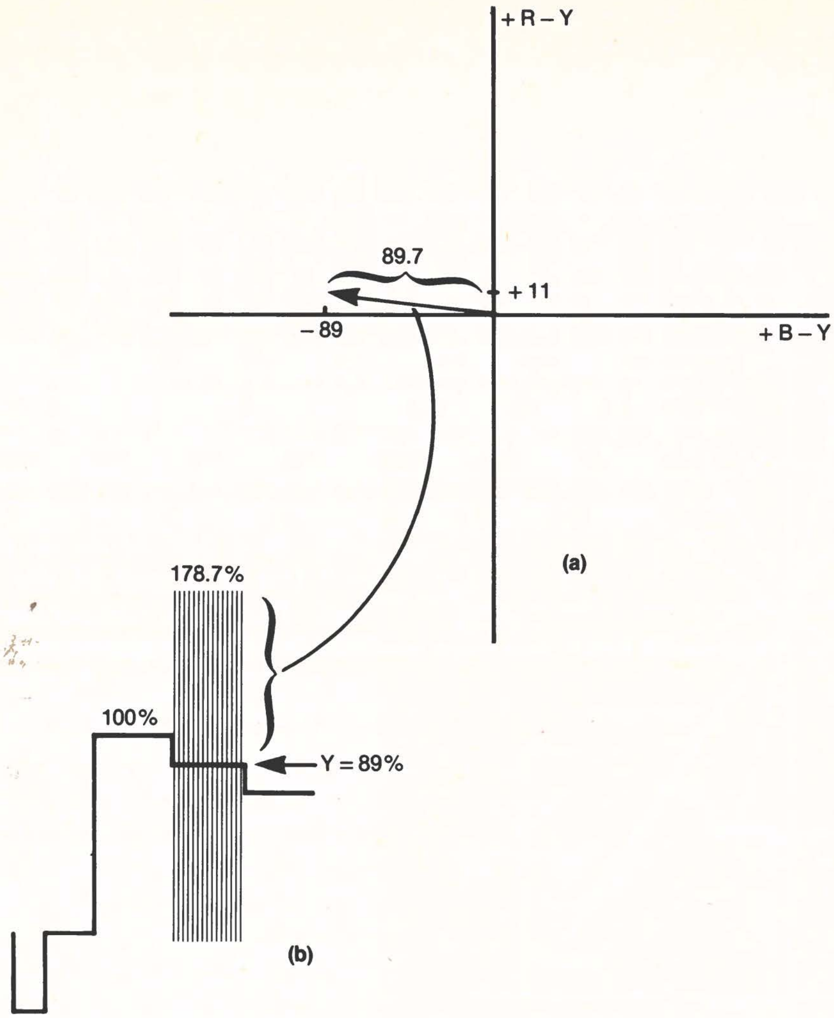


Fig. 6. Resultant of simple encoder of Fig. 4. during yellow bar creates a signal that extends too far above 100% peak white.

determined by the relative values of R−Y and B−Y. Let's take an example. When the yellow bar is scanned R−Y equals 0.11 and B−Y equals −0.89 volts. Refer back to Fig. 3. If we plot these values on the vector axes actually used we can calculate the phase angle and amplitude of the resultant yellow signal as shown in Fig. 6.

It's Too Big. The subcarrier signal that results from the addition of the outputs of both modulators is then added back to the luminance signal to form the composite video signal. But the simple modulators of Fig. 4. result in a signal that cannot be handled in regular TV channels. Look where the peak white value of the subcarrier signal extends when it is added back to the 0.89 Y signal to form the composite. This signal would be squashed by most video amplifiers let alone a 100% modulated TV transmitter.

The solution is to attenuate the color-difference signals before the modulators and then depend on the receiver or monitor circuits to restore correct relative amplitudes. A simple solution would be to cut the chrominance signals by some factor, say four, in the encoder and then multiply the reclaimed color-difference signals by the same factor in the receiver or monitor. But this acts to destroy signal to noise ratio somewhat. The originators worked out attenuation factors based on the signals affected most, like yellow and cyan having the highest Y values. The result was two attenuation factors: 0.493 for B−Y and 0.877 for R−Y. This results in a 33% extension above peak white for 100% fully saturated colors (which do not occur except in 100% color bar signals). The reciprocals of these attenuation factors must be applied to B−Y and R−Y in the decoder circuits to restore correct relative amplitudes.

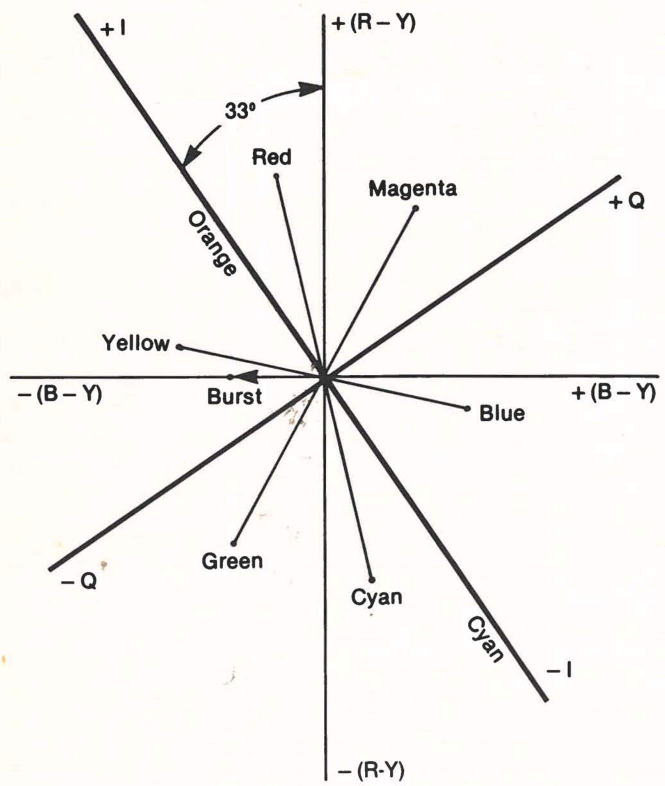


Fig. 8. I and Q modulation axes.

Now if we apply the attenuation factors to B − Y and R − Y, as shown in Fig. 8., we get a new phase angle and amplitude for the yellow bar. Also shown are the vectors for each of the remaining primary and complementary colors. Note that hue translates into specific phase angles in the multiplex system.

Choice of the Subcarrier Frequency. The subcarrier signal is present except during the time that saturation is zero (white or gray) and will produce visible effect, like CW interference, in the TV picture. To make the pattern as fine as possible the carrier should be made as high as possible. However, room must be made to preserve both sidebands of the AM signal. Since 600 kHz is alloted for full-color bandwidth, the carrier must be somewhere close to 600 kHz below the maximum video frequency of 4.2 MHz. This places the carrier at about 4.2 − 0.6 or 3.6 MHz.

To make the interference pattern even less visible, it was decided to make the subcarrier an odd multiple of ½ the horizontal line frequency. This results in a dot pattern like that shown in Fig. 7. In one field the subcarrier ends on a half cycle on one line and begins with the next half of the same cycle on the next. Thus, for sequential lines in the same field the bright spots produced by the subcarrier are 180° apart. Further, since there is an odd number of lines in the raster (525 or 262.5 per field) the interlaced lines from the next field are shifted over 90°. The visual pattern is fine lines at an angle of 45° to the horizontal which takes advantage of a peculiarity of human vision in that we cannot see fine lines at this angle quite so well as if they were straight up and down or sideways. The factor chosen is 455/2, which if multiplied by 15,750 Hz gives 3.583125 MHz. We're getting close.

Finally, the sound carrier had to be considered, since it will beat with the color subcarrier in some cases and the pattern so produced should also be as invisible as possible. Thus, it was felt that the sound carrier should also be harmonically related to the horizontal-line rate. But the harmonics of 15,750 Hz close to 4.5 MHz are still too far away to shift the sound carrier and not upset the sound systems of TV sets then in existence. It was decided to keep the sound carrier at 4.5 MHz and alter the H line rate. If 4.5 MHz is divided by 286 the line rate becomes 15,734 Hz and the sound carrier is at the 286th harmonic of the line rate. This small change in the line rate, as well as the small change in field rate (to 59.94 Hz), was well within the range of sync control for TV sets so these line and field rates have been adopted. Now if we multiply the new line rate by 455/2 we get:

15,734 Hz × 455/2 = 3.579545 MHz − the subcarrier used in the NTSC system.

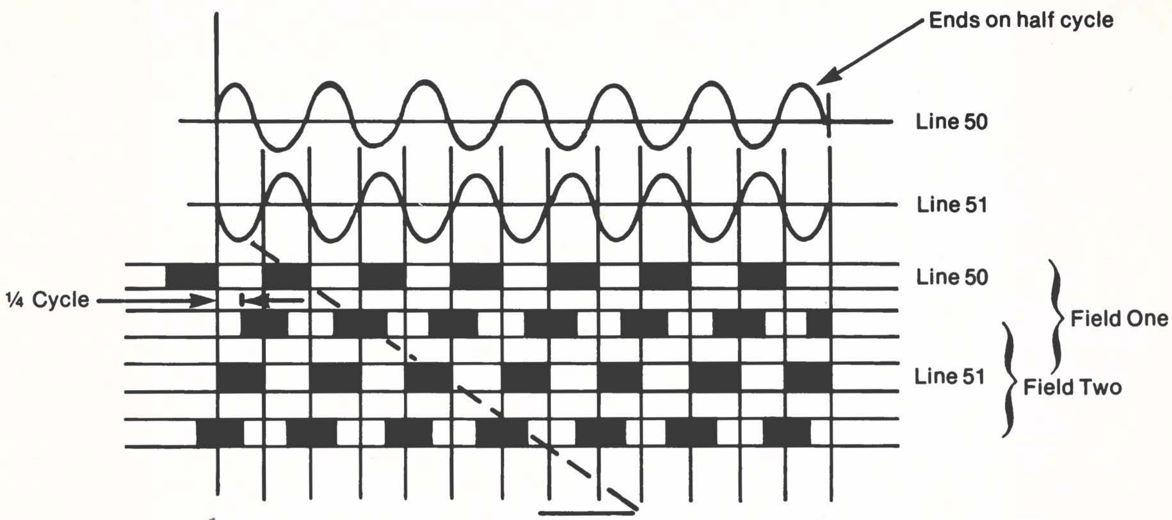
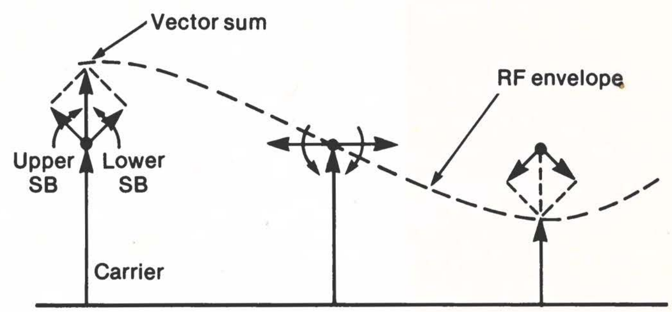
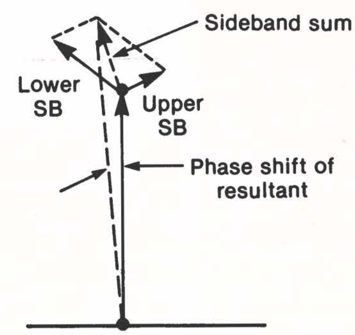


Fig. 7. Interlaced dot pattern produced by subcarrier signal when it is an odd multiple of half the H frequency.

I and Q. The actual modulation axes dictated by FCC rules are rotated some 33 degrees from the R – Y/B – Y axes, as shown in Fig. 8. To understand the reason for this it is necessary to go back to the time of the system development. Two problems faced the early workers in the field. One is that 600 kHz falls short of visual acuity in color in that we can see some hues—such as orange and cyan—out to the equivalent of about 1.2 MHz. The other problem is the effect of sideband cutting. If the carrier is kept at 3.58 MHz and color bandwidth widened the upper sideband, above 600 kHz, is cut by the overall video passband (the sound trap in TV). Loss of one sideband shifts the phase of the resultant. Consider the vector representation of an AM signal in Fig. 9. The carrier and sidebands can be represented by rotating vectors whose rotation rate depends on frequency, the lower sideband slower, the upper sideband faster. But if we use the carrier as a reference then the lower sideband vector rotates counterclockwise, the upper sideband clockwise. Note that the addition of the upper and lower sideband vectors to the carrier results in no change in carrier phase. But cut one sideband, as shown, and the resultant carrier no longer stays on the same axis but shifts as shown. A shift in resultant phase represents a shift in hue. This means that small areas of the picture as well as transitions in color that represent high-frequency color information will show a hue shift. It appears at the vertical edges of objects in the picture. The color-bar pattern can display a stripe of incorrect color at the edges of the color bars. How then to expand color bandwidth? Several schemes were tried, including phase-alternation field whereby the color signal was reversed in phase 180° on alternate fields. This phase error, being opposite in direction, then cancelled.

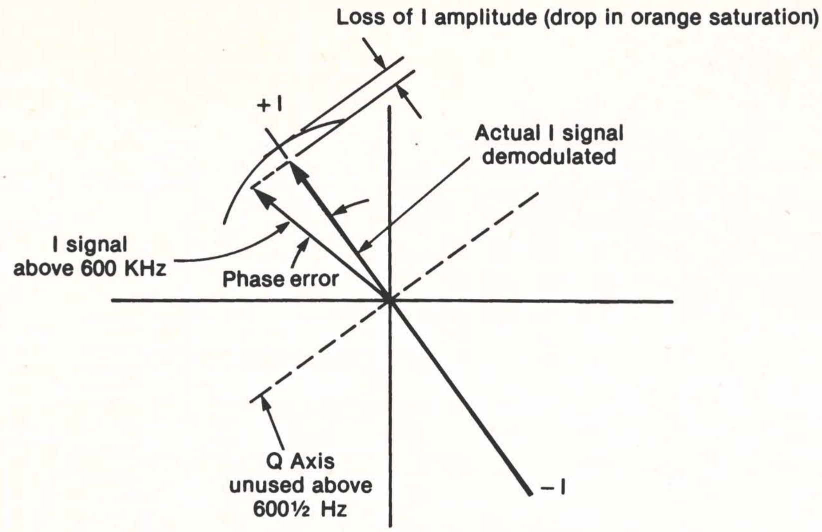


(a) Sidebands added vectorially to carrier show amplitude modulation.

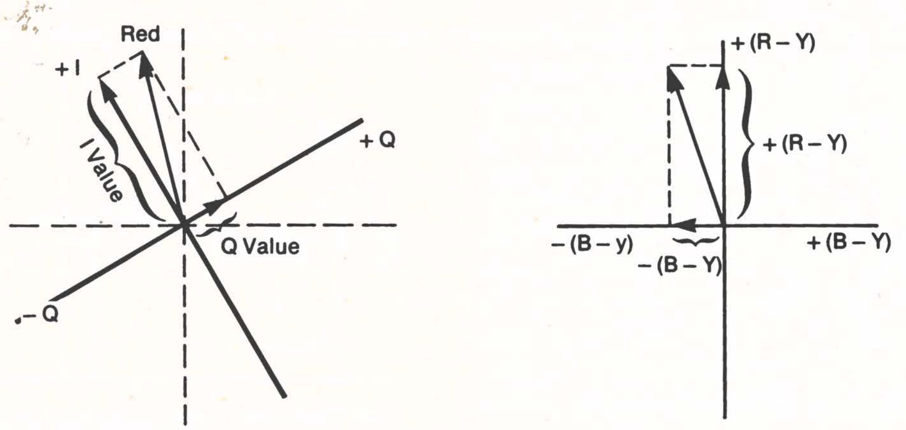


(b) Partial loss of upper sideband shifts phase of sum.

Fig. 9. Effect of partial loss of one sideband.



(a) Effect of phase error above 600 kHz in I − Q demodulation system.



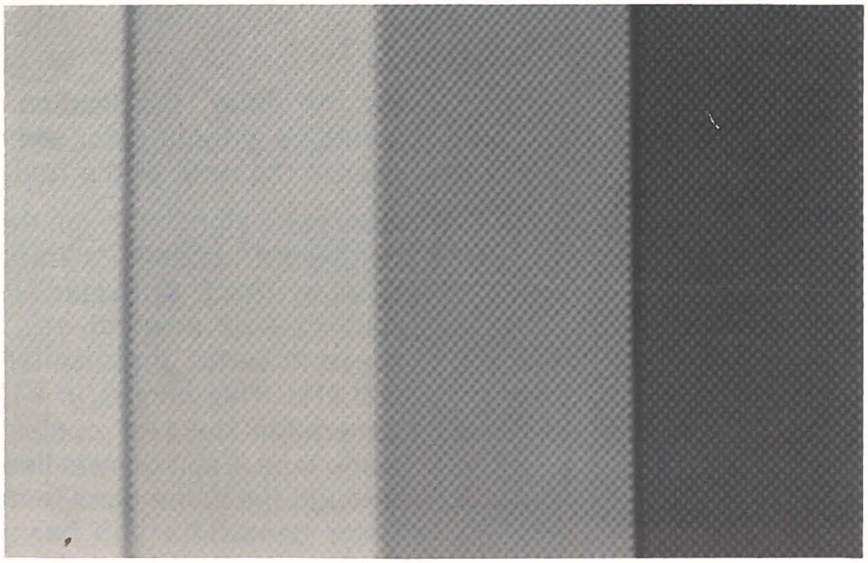
(b) Red resolved into either I and Q or R − Y/B − Y values by selection of demodulation axis.

Fig. 10. Single phase demodulation (a) and two phase demodulation (b).

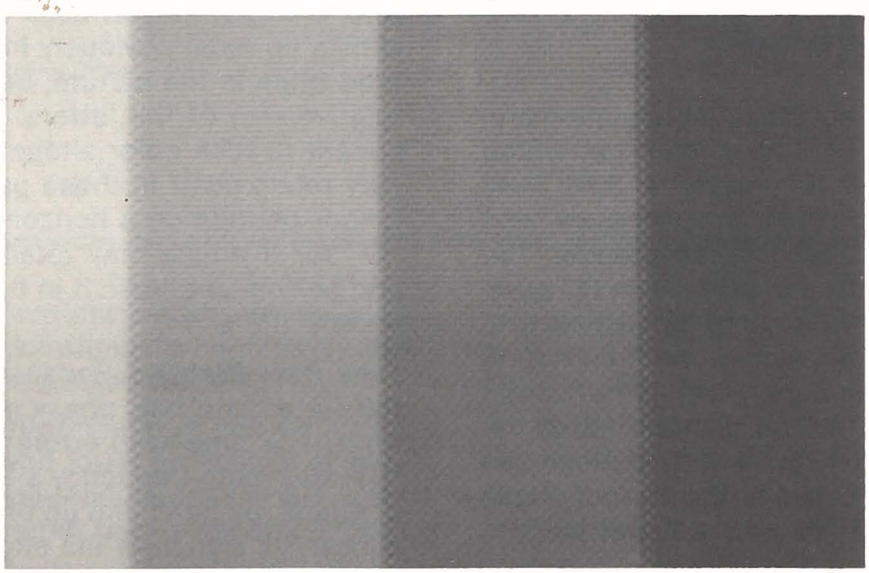
But the solution adopted was the I and Q system. Here the modulation axes are rotated as shown in Fig. 8. The I axis lies along the orange-cyan axis and the feed to that modulator has a bandwidth of 1.2 MHz. The signal applied to the Q modulator has a bandwidth of 600 kHz. A filter following the Q demodulator in the receiver is also band-limited to 600 kHz. Thus, at frequencies above 600 kHz, where phase errors are likely to occur due to sideband cutting, only one demodulator is active—the I demodulator, and the signal it produces is either orange or cyan, nothing else. If a phase error exists, it shows up as a small change in saturation for either orange or cyan as shown in Fig. 10(a).

Although the I-Q system affords the maximum in terms of color resolution, only a few receivers made use of it. The circuitry is quite complex. It requires two delay lines; one for Y and another for I as well as a complex response curve for the I channel to compensate for the partial loss of the upper sideband. Most receivers and monitors demodulate the color-difference signals directly, or something very close to it. It is important to realize that any particular hue, red for example, can be resolved into two vector components both in modulation or demodulation. Fig. 10(b) shows red represented by both R − Y/B − Y and I/Q values. The encoder in most color cameras designed for industrial applications also operates on the R − Y/B − Y axis.

Thus, for practical reasons, color resolution has been sacrificed somewhat and the multiplexed color signal actually used has a bandwidth of about 1 MHz, 500-kHz each side of the subcarrier signal.



(a) Subcarrier dot patterns



(b) 3.58 MHz trap switched on

Fig. 11. Effect of 3.58 MHz trap in a wide-band black-and-white monitor.

Suppressed Carrier and Burst. It was noted earlier that the chrominance signals are zero for neutral white and gays. Refer back to Fig. 3. Also the modulators are balanced so that no subcarrier is produced when white or gray is scanned. The carrier is in fact supressed or cancelled out and only color sidebands are produced. Of course, when you look at the color-bar signal with your scope, you see 3.58 MHz sine waves for the duration of the bar. In fact, since the color is not changing in these broad areas, the sidebands have contracted to the subcarrier frequency. You can get a good idea of the existence of sidebands by looking at the dot pattern formed of the subcarrier signal using color bars and a wide-band black-and-white monitor. See Fig. 11(a). The dot pattern can be clearly seen and appears to crawl upwards due to the strobe effect of line progress. If you turn on the 3.58 MHz trap in the monitor the dots disappear but remain at the edges of the bars, like bubbles rising in a champagne glass. See (b) of the figure. The reason is that the outer sidebands carry the energy at the transitions, where things are changing, and these sidebands are outside the skirts of the trap.

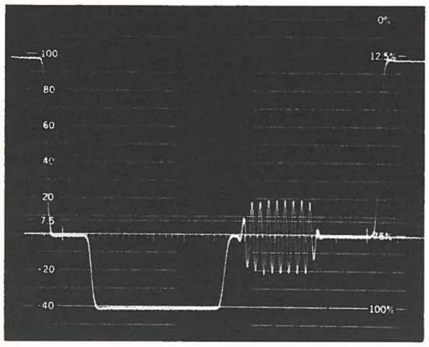


Fig. 12. Burst signal.

The carrier is put back in the demodulation process by a source of CW signals generated locally. The source is usually a 3.58 MHz crystal oscillator, locked in frequency and phase to the carrier signal in the encoder. The reference supplied for this purpose in the composite signal is burst, a sample of about 8-10 cycles of subcarrier signal at the –(B-Y) phase, placed on the back porch of horizontal blanking. See Fig. 12. The decoder locks the local oscillator to that signal and develops two or three outputs adjusted to the correct phase to demodulate the desired color-difference signals.

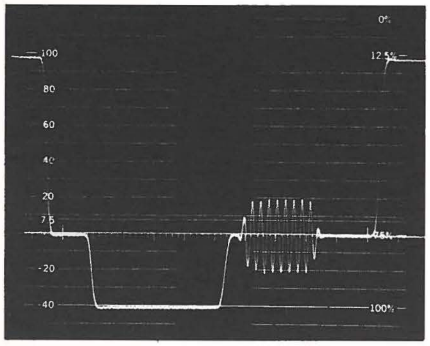
Chroma Bandwidth and Delay. A time delay is introduced when bandwidth is restricted. Take the simple example of a square wave applied to the simple low-pass filter of Fig. 13(a). It takes time for the capacitor to charge up at the leading edge, and time for it to discharge at the trailing edge. The output square wave, in addition to losing its rapid rise and fall time, has effectively moved over in time.

When the wide-band luminance signal is processed in a receiver it has to be delayed so that it will reach the drive elements of the picture tube at the same time as the slower color signal. See Fig. 13(b). Thus, it puts the rather fuzzy color in the middle of the sharp outlines provided by the luminance signal. Were it not for the delay, the leading edges of objects would be without color while color would spill over to the right of the trailing edges.

If we put a signal through the same filter twice, bandwidth becomes a fraction of that of the filter by itself. Consider two low pass filters that are 3 dB down at, say, 500 kHz. If we put these in series the resultant is 6 dB down at 500 kHz. This occurs in VTRs when multiple-generation dubs or copies are made of the same tape. Each copy is like putting the signal through the same band-restriction filter again. Color bandwidth and hence color resolution gets narrower and lower. Chroma delays, therefore, also get longer. Loss of color resolution shows up most obviously in the letters of colored titles in the picture, depending upon the relative size of the letters. Very small letters appear to lose color altogether, larger letters may retain color in those parts that represent longer periods on a horizontal line. The letter "O" for example may retain color at the top and bottom , but lose it in the vertical sides as shown in Fig. 14.

Time Base Stability. Because subcarrier phase translates into hue, phase error results in hue error. The time-base errors introduced by the VTR alter both frequency and phase of the color signal, by bunching up or spreading out the subcarrier signal as the short term variations in head-to-tape velocity occur. From a practical standpoint the phase reference, burst, and the chroma information in the line that follows are subject to the same change of phase. However, the automatic frequency and phase control (AFPC) system in the receiver or monitor does not correct line by line and responds slowly to abrupt changes in subcarrier phase. As a result, time-base errors translate into phase errors at random locations in the picture.

Short term phase errors are a form of noise that results in hue error. Amplitude noise, such as that caused by mistracking, is also present. Thus the color signal is subject to two forms of noise: a phase component and an amplitude component.



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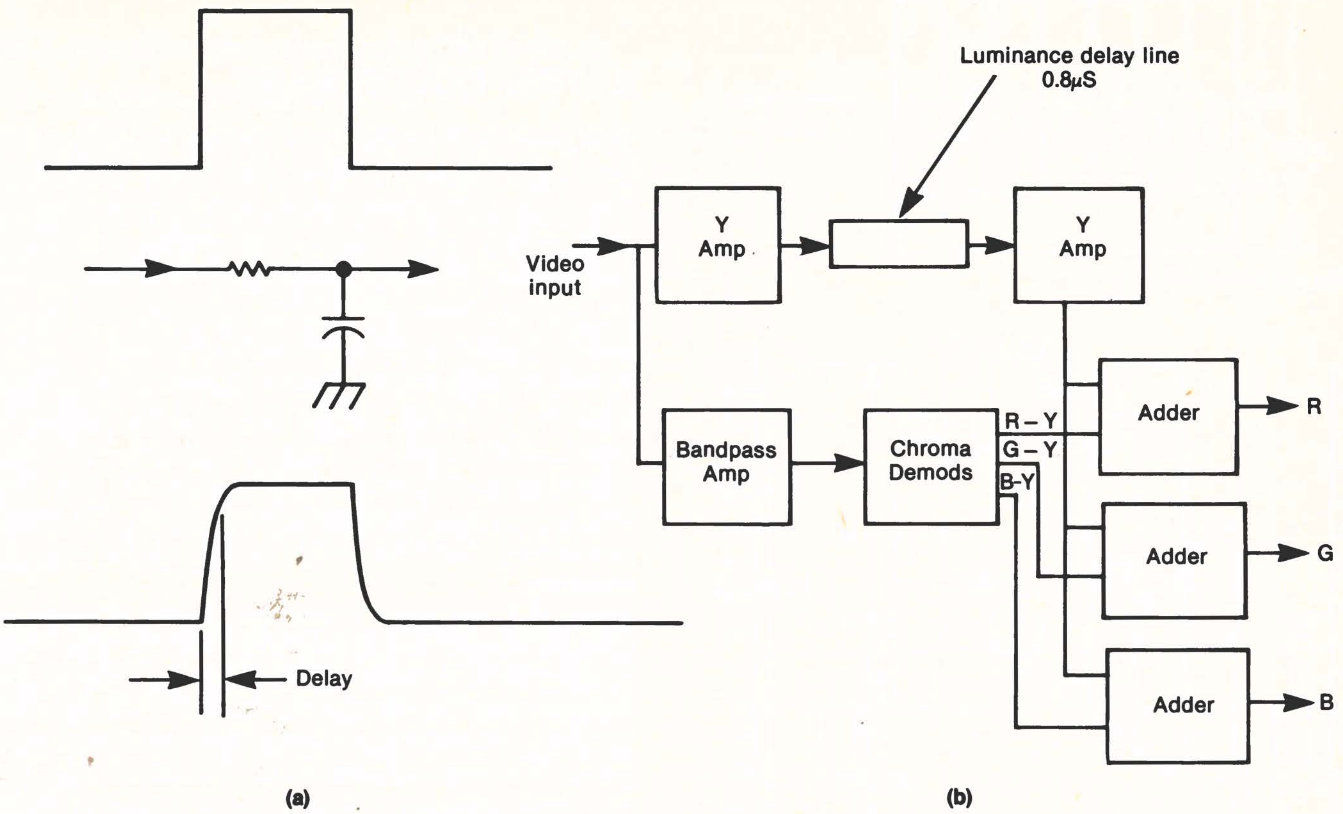


Fig. 13. Luminance signals are delayed to match delay introduced into narrow-band chroma circuits.

Summary. The important factors to keep in mind when the color signal is handled by the VTR can be summarized as follows.

1. Chrominance information is carried in the form of upper and lower sidebands of two-phase amplitude-modulated signals centered at a subcarrier frequency of 3.579545 MHz.
2. The practical effective bandwidth of the multiplexed chroma signal is about 1 MHz, 500 kHz each side of the subcarrier.
3. Further restrictions of chroma bandwidth result in lower chroma resolution and longer chroma delays.
4. The amplitude of the chroma signal relates to the degree of saturation in the color.
5. The phase of the chroma signal, with respect to the reference burst, determines hue.
6. Time-base error introduces instantaneous changes in phase that the AFPC system in the receiver or monitor cannot follow and results in random hue errors in the picture.
7. Chroma noise has both phase (hue error) and amplitude components.

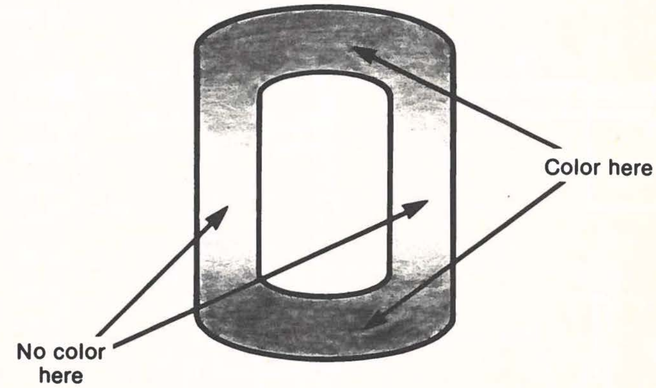


Fig. 14. Visual effects of poor color resolution in small letter "O".

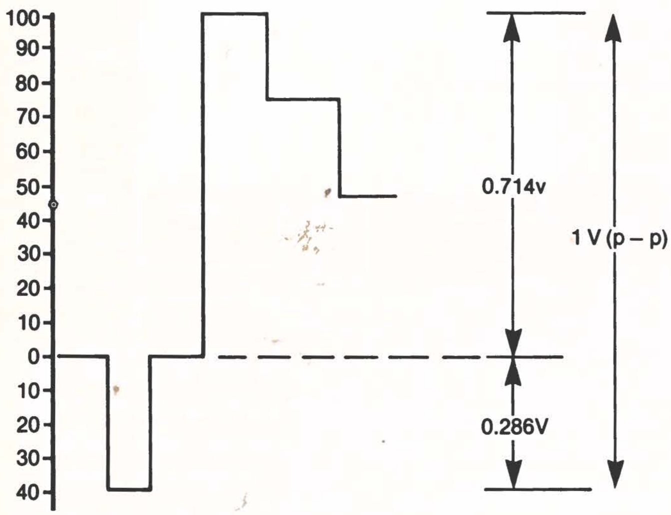


Fig. 15. IRE units translated into a 1V (p – p) signal.

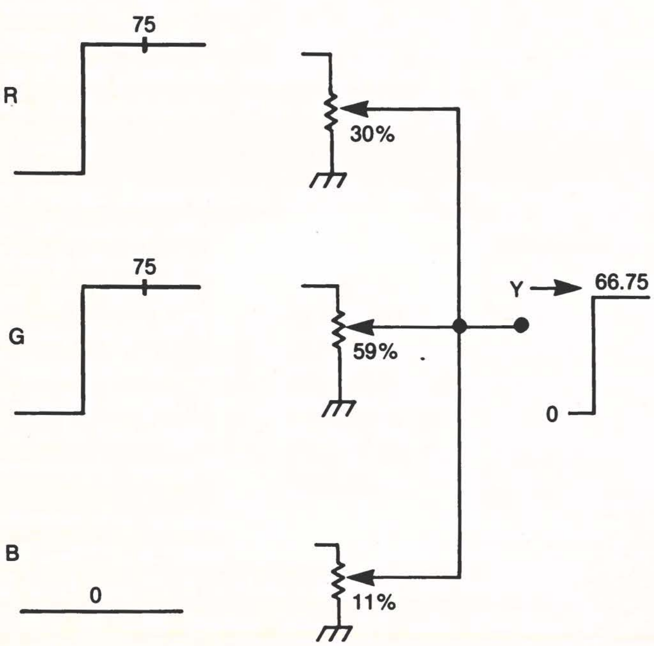


Fig. 16. Calculating Y for 75% yellow bar (neglecting setup).

2. 75% COLOR BARS

The standard color test signal is 75% color bars. We learned earlier that 100% color bars result in subcarrier peak excursions that extend some 33% above peak-white during the yellow bar. This places an unnecessary burden on video signal-handling equipment of all types because fully saturated signals at 100% levels are not encountered in practical camera signals. For this reason the use of fully saturated color bars at 75% amplitude has been universally adopted. Since this is the test signal you will be seeing most often, it's worth becoming familiar with some of its key attributes.

IRE Units. Before we start, let's review some basic aspects of the units used to measure the *relative* amplitude of the video signal. By convention the region between blanking and peak white is assigned a value of 100 units. See Fig. 15. With this as a basis, sync extends down from blanking a total of 40 of the same units. These are relative values and can be assigned to any particular voltage level. If, for example, the total signal is 1 V(p-p), the region from blanking to peak white is:

$$\frac{140}{1\text{ V}} = \frac{100}{X}$$

$$140\,X = 100\text{ V}$$
$$X = 0.714 \text{ volts (approximately 0.7 volts)}$$

Similarly, the voltage amplitude of sync for the same 1 V(p-p) signal is:

$$\frac{140}{1} = \frac{40}{X}$$

$$140\,X = 40$$
$$X = 0.286 \text{ volts (approximately 0.3 volts)}$$

For convenience, waveform monitors are calibrated directly in IRE units and we will use them in the calculations for 75% color bars that follow.

What 75% Means. The RGB signals going into the encoder are each simply 75 IRE units rather than 100. Everything else is the same and they will result in full saturation. That is, blue is cut off during the yellow bar.

The Y signal is generated using the formula:

$$Y = 0.30R + 0.59G + 0.11B$$

For example, during the yellow bar, R = 75 units, G = 75 units and B = 0 units. See Fig. 16. Adding 0.30 x 75 and 0.59 x 75 results in a Y value for yellow of 66.75. But a look at the standard Y signal, in accordance with EIA RS-189-A shows a Y value of 69. See Fig. 17. The reason for our error is failure to include *setup* in our calculations. Setup raises the black limit of all signal excursions above blanking. It was adopted to avoid cable-microwave transmission link problems early in the practical application of color TV and has become standardized at 7.5 IRE units.

To include setup we must subtract 7.5 units from 100 to find the available signal swing. This is 92.5 units. Now we take 75% of this to find the 7′ value. R and G are now 69.375 units. Now we can recalculate Y for yellow as follows:

$$Y\text{ (yellow)} = 0.30 \times 69.375 + 0.59 \times 69.375 = 61.74$$

This must now be added to the setup to get the final value.

Thus:

$$Y\text{ (yellow)} = 61.74 + 7.5 = 69.24$$

This is rounded off to a nominal 69.

If you are curious, see if you can calculate Y for the remaining color bars.

The phase angle and amplitude of the chrominance signal is calculated by laying out the values of R – Y and B – Y on the modulation axes and doing some trigonometry. Using values, without setup added, for Y, R and B during the yellow bar, we get:

$Y = 61.74$
$R = 92.5 \times 0.75 = 69.375$
$B = 0$
Thus $R - Y = 69.375 - 61.74 = 7.635$
$B - Y = 0 - 61.74 = -61.74$

To these values must be applied the attenuation values given earlier.

$R - Y = 7.635 \times 0.877 = 6.696$
$B - Y = -61.74 \times 0.493 = -30.44$

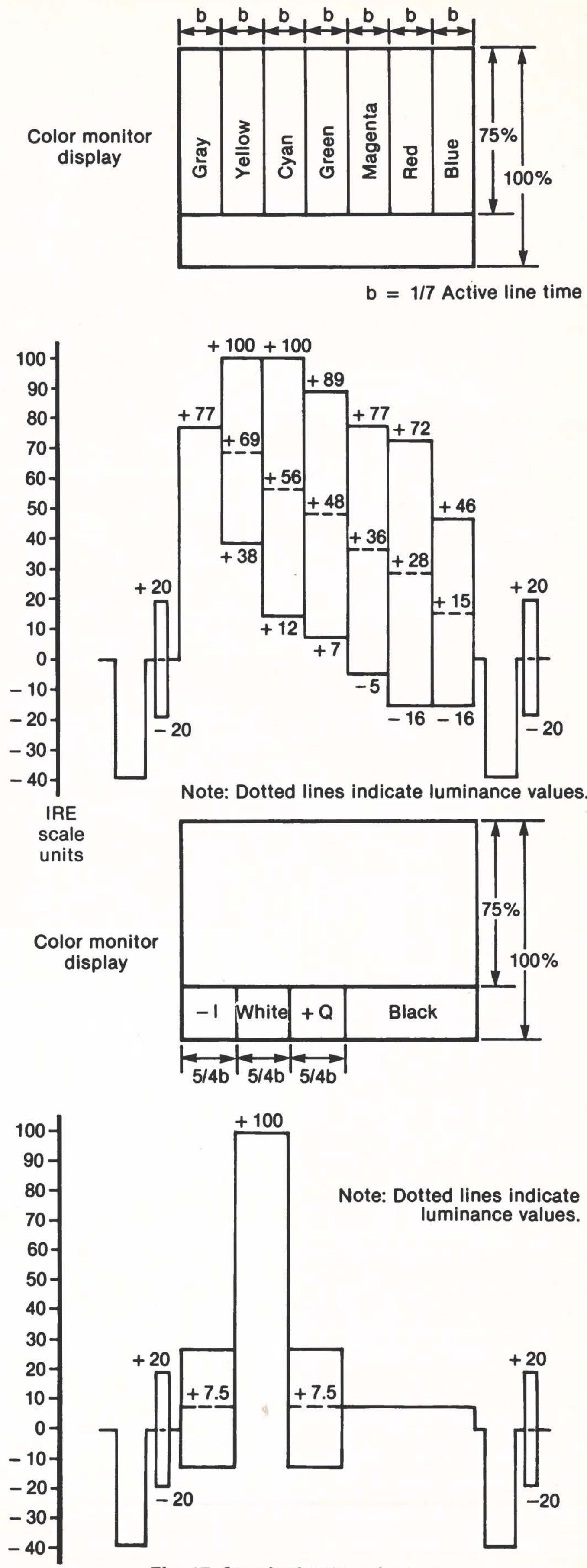
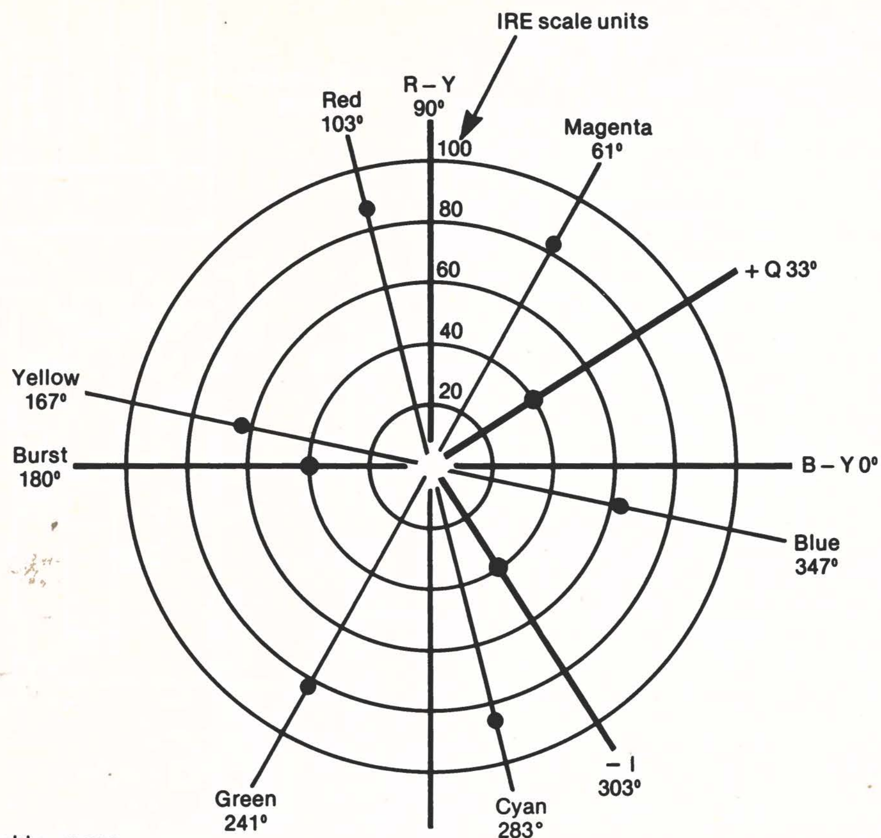
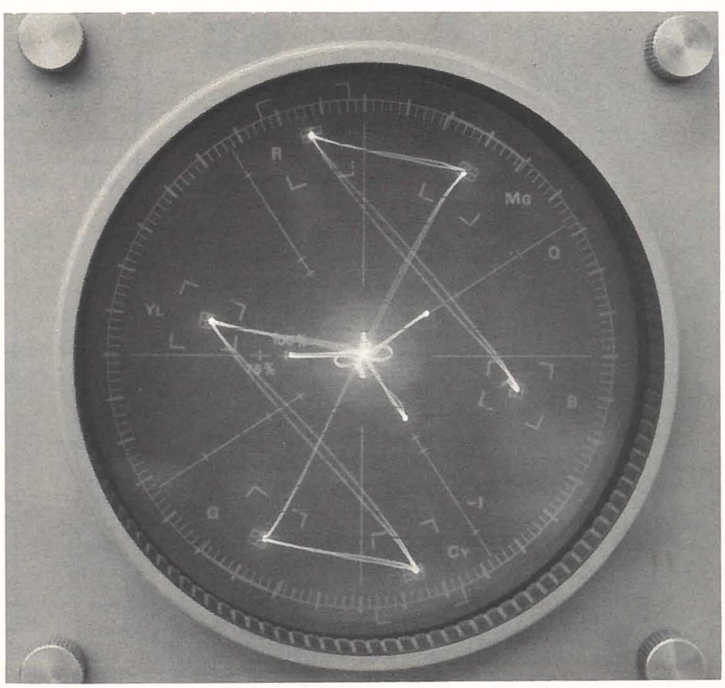


Fig. 17. Standard 75% color bars.



Vector relationship among
burst and chrominance components

(a)



(b)

Fig. 19. Vectorscope display of 75% color bars.

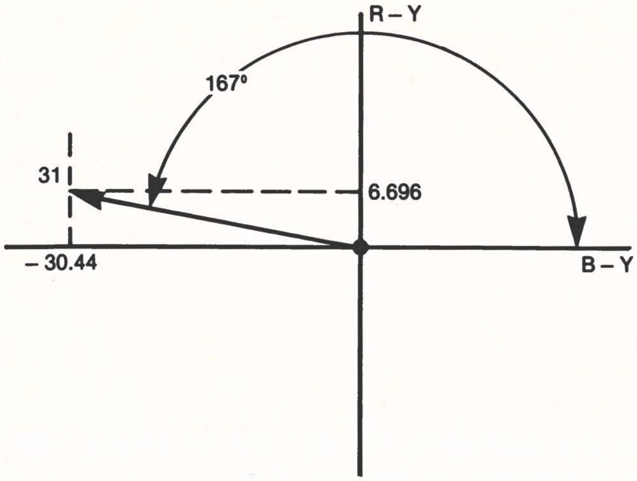


Fig. 18. Amplitude and phase of yellow bar.

These values are layed out on the modulation axes. From these values, the peak value of the yellow chrominance signal works out to 31 units, or 62 units, (p-p) and the phase angle is approximately 167° (180° – 13°). See Fig. 18. A vector representation of all colors in the bar pattern with peak-to-peak value for chrominance is shown in Fig. 19. This display is produced by the vectorscope, which is a precision demodulator that applies B – Y to the horizontal areas and R – Y to the vertical axis of a calibrated oscilloscope.

In the standard color bar display, the 75% color bars are presented on the top 3/4ths of the display. The lower quarter contains a 100% white bar as well as I and Q signals with no Y component (just setup). This combination makes it extremely easy to see when chrominance and luminance levels are correct when looking at the composite signal. Look at the yellow bar in Fig. 20. The peak value of chrominance (31 units), when added to the Y value of 69 yields 100. Thus, when chroma level is correct the top of the yellow bar is even with the 100% white bar. The same occurs for the cyan bar (56 Y units + 44 chroma units). Keep this point in mind because color adjustments in VTRs are largely amplitude settings, one being the relative amplitude of Y and C. By looking at the 100% white bar superimposed on the chroma signal you can tell at a glance when Y and C have the right mix—the tops of the yellow and cyan bars line up with the 100% white bar.

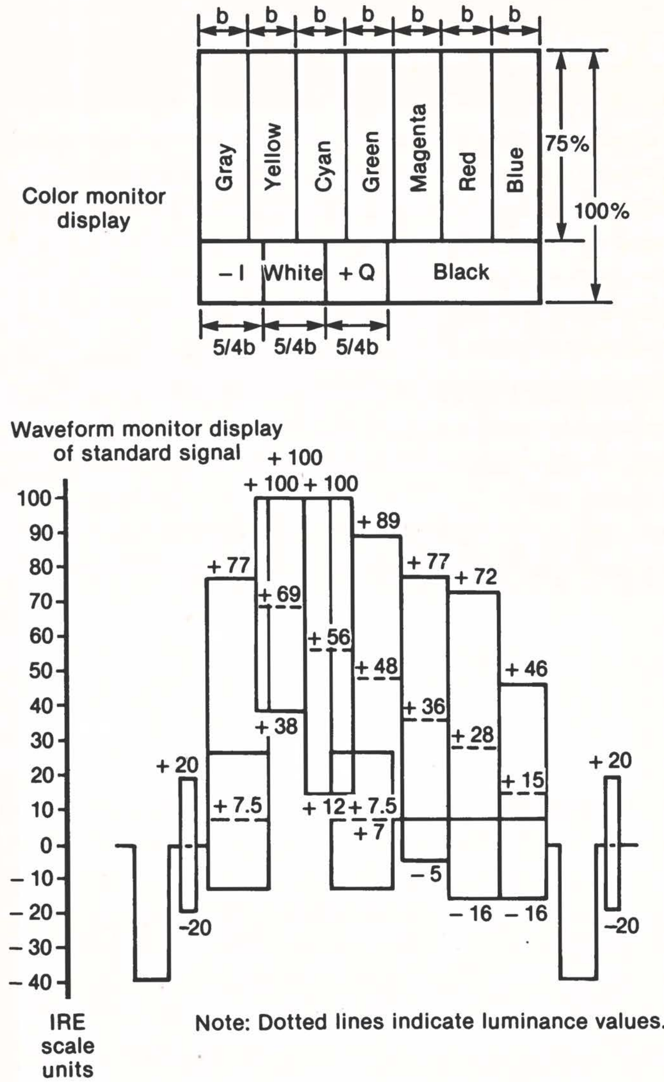


Fig. 20. Composite 75% color bars: peaks of yellow and cyan bars line up with top of 100% peak white bar.

Burst amplitude, at a peak-to-peak value of 40 IRE units, can also be used as a guage. It should be equal to the sync value, from blanking to sync tip. But this requires a closer look at the scope graticule, and perhaps a change in trace centering to verify the correct Y/C mix.

3. COMB FILTERS

One of the outcomes of making the subcarrier frequency an odd multiple of the H rate, in addition to making the dot pattern less visible on the screen, is that the color sideband signals fall in between the harmonics of the H signal. The H harmonics constitute video information up to 4.2 MHz. This phenomena is known as *frequency interlace.*

In the region between 3.2 and 4.2 MHz where both chroma and luminance signals coexist, it is difficult by conventional means to separate these signals. For example the bandpass amplifier in a TV set amplifies the band between 3.2 and 4.2 MHz. It amplifies the multiplexed chroma signal alright, but also the Y components that exist in that range. Similarly, to trap or filter the chroma signal out of the Y amplifier chain removes Y information vital to preserving high luminance resolution. It is a fact that the 3.58 MHz trap in the luminance amplifiers of most TV sets and monitors takes out the color subcarrier (you don't see the subcarrier dot pattern on the screen of a color set), but luminance resolution suffers as well. Most TV sets have a luminance resolution of only about 250 lines. This corresponds to a luminance bandwidth of only about 3.1 MHz.

The comb filter takes advantage of the frequency interlace situation to provide a way of separating chrominance and luminance signals. It is really a delay line that provides a delay of 1 H or 63.5 μsec.

Take a look back at Fig. 7. Here you learned that one line in a field contains a number of subcarrier cycles plus a half cycle. The next line in the same field starts out with the second half of that cycle. Thus, at any point on a line the subcarrier is 180° out of phase with the subcarrier on the next line.

What the comb filter does is add, or subtract, the signal on one line to the signal of the previous line that has been delayed 1H. See Fig. 21. If these signals are added the chrominance signals, being 180° out of phase will cancel; the luminance signals, on the other hand, double. If the direct and delayed signals are subtracted the opposite occurs: the luminance signals cancel and the chrominance signals double. The effect is the same for the luminance and its harmonics, or the chroma sideband signals. The response curve of the comb filter looks like that shown in Fig. 22. Its comb-like appearance gives the device its name.

Comb filters are used in high-resolution monitors and in VTRs to separate luminance and chrominance signals while preserving luminance bandwidth. In effect the chroma sidebands are "combed-out" of the luminace signal. In the home videocassette machines, comb filters play a vital role in achieving track-to-track isolation for the 688 kHz chroma signal. These machines do not employ guard bands between adjacent video tracks and an azimuth error between video heads serves to provide isolation in the range of FM luminance signals. In the zero guard-band systems the chroma pickup from the adjacent track is made to have the same phase from line to line. The comb filter is set up as a subtractor. It then cancels cross talk signals from the adjacent track but doubles chroma signals from the selected track.

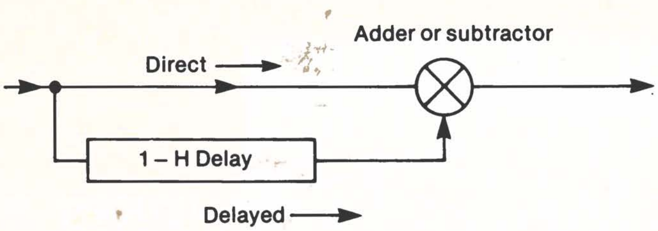


Fig. 21. Basic comb filter.

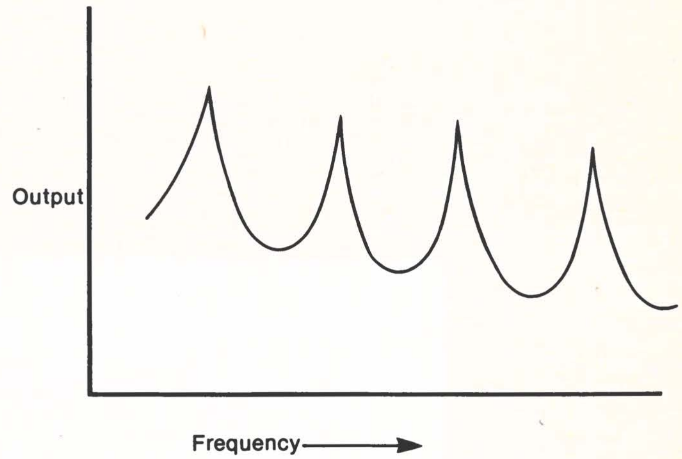


Fig. 22. Comb filter response.

A 63.5 μsec delay is too long to achieve by purely electrical means. The delay is achieved by propagating the signal through a ceramic substrate in the form of a sonic wave. Ceramic transducers at each end of the propagation path change the electronic signal into a sonic signal, and back into an electronic signal again. Fig. 23. shows a comb filter with the plastic cover removed. The path between transducers is somewhat like the route taken by a billiard ball, bouncing off the edges of the ceramic panel. Signal polarity can be selected (to add or subtract from the direct signal by simply reversing the leads to either transducer).

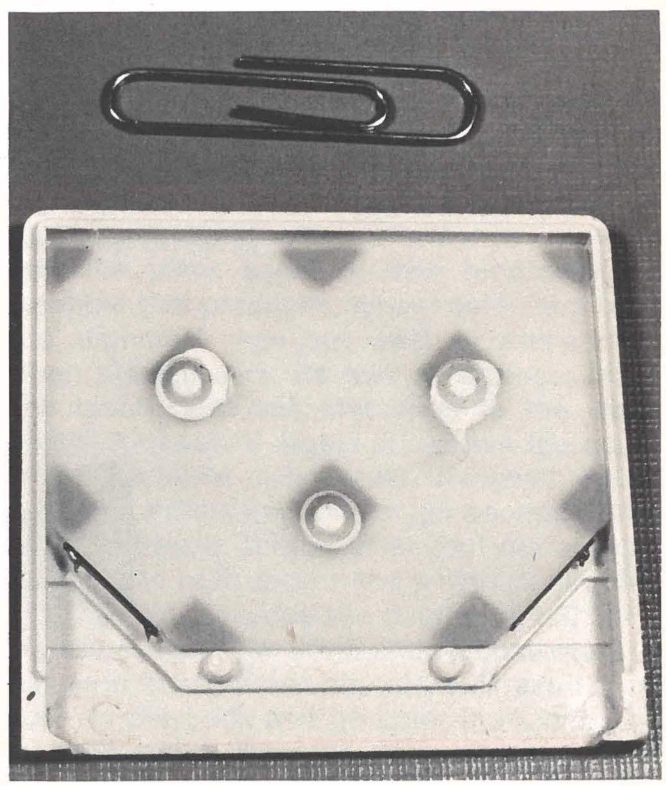
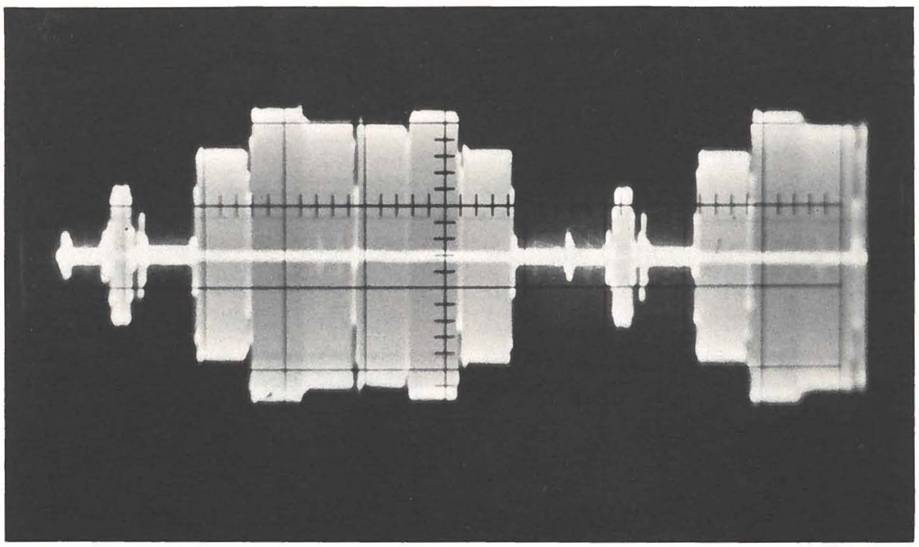
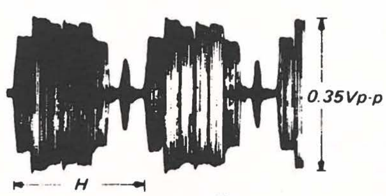


Fig. 23. Betamax comb filter with cover removed.



(a) Appearance of chroma signal after the Y signal has been separated.



IC3 9

(b) Typical schematic waveform with peak-to-peak voltage given.

Fig. 24. Chroma signal separated from luminance. Peak-to-peak voltages apply to red and cyan bars.

4. TROUBLESHOOTING THE COLOR PROCESSOR

As you learned in the tape for this lesson, the color signal is not demodulated in either direct or color-under processes. In the direct system the color signal remains intact, accompanying the luminance signal, so loss of color also affects the luminance signal where the chroma signal is carried. In the color-under process, the chroma sidebands are separated and then simply reclocated to a new center frequency of 688 kHz for record purposes. In playback the heterodyne process is reversed, and up conversion beats the sideband signals at 688 kHz back up to 3.58 MHz. They then rejoin the luminance signal to produce the composite output signal. At no time is the signal demodulated to reclaim the original chroma signals (R – Y, B – Y and G – Y). Nor do the chroma sidebands ever become separated from the reference burst signal.

This makes troubleshooting relatively easy. It boils down to signal tracing with a check of signal amplitude at each step in the record or playback circuits. Once the chroma signal has been separated from the luminance signal it resolves itself around zero, or whatever d-c level exists in the circuit, and appears as shown in Fig. 24a. Since the red and cyan bars in the color-bar signal have the largest peak-to-peak amplitude, (refer back to Fig. 20.) chroma waveform voltages are usually given in terms of the red and cyan bars, as shown in *b* of the figure.

Record/Playback Troubles. Trouble can be localized to record or playback circuits by comparing what the machine produces when playing back an alignment tape, or a tape known to be in good shape, with performance when the machine plays back its own recordings. A machine that produces normal color bars from the alignment tape but weak or noisy color when playing back its own recordings, likely has insufficient 688 kHz drive to the video heads. A check of signal drive from the color-record amplifier is in order. However, color-under machines have one major section of the color processor that is often (but not always) common to both record and playback circuits. This section provides the source of 4.27 MHz signals for both the down and up convertors. A failure in the common circuitry will result in no color in playback and no color in record. The latter would be detected when a tape made in the machine in question is played on a machine known to be good.

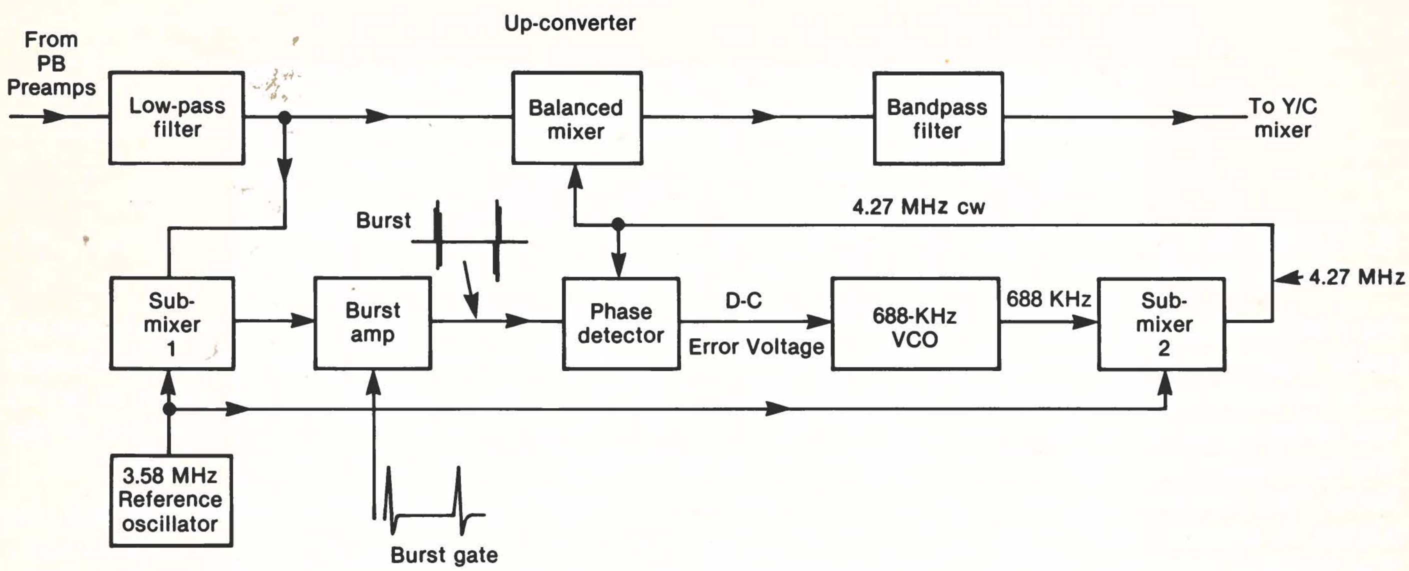


Fig. 25. Basic APC system.

AFC/APC System. The source of CW drive to the up convertor in playback is an APC system, in many cases augmented by an AFC system. Faults in this system can result in frequency as well as amplitude errors in the reproduced color, and large frequency errors result in complete loss of color. Consider the simple APC system shown in Fig. 25. The heart of the system is the up convertor. For it to function it must have two inputs, the 688-kHz drive from the preamps and ACC system and the 4.27 MHz drive from sub-mixer 2. The sub-mixer also has two inputs, both from local oscillators. In addition to the amplitudes of the CW feeds to the sub mixer, the frequency at which these sources operate is vital. The 3.58 MHz oscillator should be checked using an accurate counter. This oscillator is of particular importance in determing the subcarrier output frequency of the machine. Large errors will cause loss of color lock in the monitor, but small errors, in the range of 100 Hz, can cause hue errors in the monitor because the monitor is locking up on the edge of its pull-in range. The effect can be quite different between monitors or TV sets of different design. Hence a routine procedure includes a frequency-accuracy check of both the 3.58 MHz reference oscillator and the 688-kHz VCO. Procedures are always given in the service manuals for checking the frequency of the fixed and voltage-controlled oscillators.

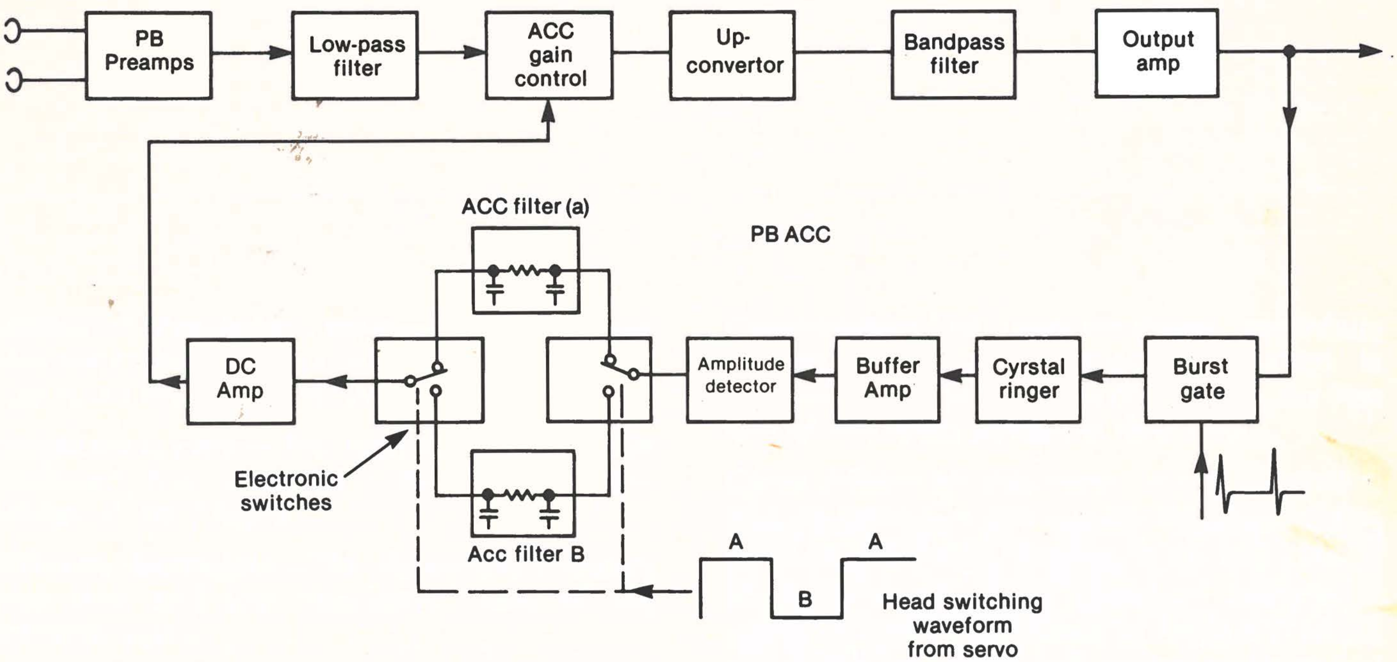


Fig. 26. Basic AFC/APC system.

The AFC/APC system shown in Fig. 26. produces the 4.27 MHz in a different way. The submixer has two inputs but one is from an AFC system that is driven from horizontal sync. The other is from an APC loop that compares the final 3.58 MHz product with a fixed reference oscillator to correct residual phase errors. Loss of color lock in the monitor suggests a fault in the AFC system which could include loss of horizontal-sync input. A thorough check of the AFC loop includes a frequency check of the VCO under free-running conditions (no sync input) and a check for the two inputs to the phase detector that generates the error voltage. A fault in the APC loop in systems such as that shown in Fig. 26. can be more subtle. Failure to correct residual phase errors shows up as faint horizontal bands of hue error, most easily seen in the magenta bar of the color-bar display. Here again the VCO must be checked for correct free-running frequency, as well as the 3.58 MHz reference oscillator. The phase detector must have its two inputs and have its correction voltage applied to the VCO. In practical cases, many of the circuits are inaccessible for direct checks and the troubleshooting procedure boils down to checking for correct input drives and if they are present, the IC in question must be replaced.

Color Flicker. Unlike the FM luminance system, the color signal is recorded directly in color-under machines. As such the playback signal is subject to variations in head sensitivity and other factors that affect the amplitude of the signal picked up by the video heads. A difference in playback amplitude between video heads is expected and results in 30-Hz flicker in color saturation. This flicker is eliminated by a rather elaborate ACC system in the circuits between the playback preamps and the up converter. The appearance of color flicker is therefore localized to circuitry between the preamp balance pot and the 688 kHz input to the up converter.

To sum it up, color troubleshooting starts at the frequency converter and follows the two signal paths that feed these converters. It's not unlike troubleshooting the mixers in radio or TV receivers, with one important difference, the signals are of sufficient amplitude, and in a low-enough frequency range, to permit direct observation with almost any oscilloscope.

CONGRATULATIONS!

This phase of your involvement with video is complete with this booklet. You are to be commended for your perseverence, and we hope that it has been an interesting and rewarding experience for you. Your work in video may be frustrating at times and the machines may appear so complex as to defy understanding at first. But regardless of complexity they are all extensions of the information you have now acquired. We wish you the triumphs of problems solved and satisfaction of work well done.

Sony
Basic Video Recording Course
Booklet 8
Glossary of Color Signal Processing

Balanced Modulators, color—Modulators that are electronically adjusted to produce no output when the chrominance signals are at zero.

Brightness, color—The total energy, direct or reflected, that is carried in the color signal in terms of the Y signal.

Chroma Bandwidth—The difference between the high and low frequency limits of the chroma signal.

Chroma Delay—A time delay introduced when the chroma bandwidth is restricted by passage through a low-pass filter.

Chrominance—The color information used to change the monochrome (Y) signal into a color signal.

Color Bars, 75%—The standard color test signal used in the NTSC system. 75% of the peak level is defined as the input level for any of the primary colors.

Color-Difference Signals—The signals obtained by subtracting the composite luminance signal Y from the primary color signals (R, G, B); R – Y, B – Y, and G – Y. See Chrominance.

Color Flicker—A 30 Hz periodic change in the color saturation due to video preamp imbalance between the two video heads.

Color-Under—The color-recording technique in which the chrominance information is heterodyned down from 3.58 MHz to the low end of the video passband (688 kHz).

Comb Filter—An electronic circuit consisting of a 1H delay line and a summing point, which adds (or subtracts) the interlaced video signal to separate the chrominance (or luminance) signal. The response of the circuit resembles the teeth of a comb.

CW Interference—Continuous Wave Interference; RF interference generated by another carrier signal appearing in the waveform.

Direct-Recording—A broadcast videotape technique in which the entire composite signal, including color, is processed and recorded.

Frequency Interlace—The method by which chrominance (color) and luminance (B&W) information are interwoven within the same bandwidth.

Hue, color—The predominant wavelength in the color spectrum in a color video waveform. In the NTSC system this is determined by the phase angle.

IRE Units—Institute of Radio Engineers standard of reference used as a measure of the relative amplitudes of a video signal.

NTSC—National Television Systems Committee; a committee that formulated the present U.S. color television standards.

Saturation, color—The depth of a color or spectral purity (freedom from dilution with white). This refers to the relative amplitude of the chrominance signals.

Set-up—The difference between the black level and the blanking level (no video) which is necessary to practically implement video electronics. Sometimes expressed as a ratio of the black/blanking magnitude to the blanking/peak white magnitude.

Sideband Cutting—Limiting the bandwidth of one side of a sideband pair by attenuating one sideband, thus unbalancing the pair.

Spectral Sensitivity—The sensitivity of visual receptors (the eye, the video camera) as a function of different light frequencies (color).

Suppressed Carrier—A technique in color recording in which the carrier is attenuated or cancelled and only color sidebands are produced.

Time-Base Stability, color—The ability of a VTR to minimize recorded errors due to mechanical errors in the transport. These errors result in both frequency and phase deviations of the color signals, which cause hue errors.

Vectorscope—A precision demodulator that applies B-Y to the horizontal axis and R-Y to the vertical axis of an oscilloscope.

Visual Acuity, color—The ability of human vision to discern colors at varying distances and in different shapes.

SONY
BASIC VIDEO RECORDING COURSE
SELF-TEST NO. 8
COLOR SIGNAL PROCESSING

(Circle your answer.)

1. The approximate bandwidth of the down-converted chroma signal in an industrial VTR is: (a) 1 MHz; (b) 500 kHz; (c) 688 kHz; (d) 3.58 MHz.
2. The approximate bandwidth of chroma signals fed to the picture tube of a TV set driven from an industrial VTR is: (a) 1 MHz; (b) 500 kHz; (c) 688 kHz; (d) 3.58 MHz.
3. In the color-under process the effects of time base error are reduced by: (a) the use of a time-base corrector; (b) the use of a highly stable 3.58 MHz oscillator; (c) amplitude modulation of the chroma signal; (d) an up-convertor fed with a source of CW that has the same jitter components as the playback signal.
4. The 688 kHz down-converted chroma signal is applied to the tape: (a) as an FM signal; (b) on a separate track; (c) as an addition to the FM luminance signal; (d) by separate chroma video heads.
5. The AFC system in an AFC/APC processor follows jitter in the: (a) 688-kHz chroma signal; (b) playback horizontal sync signal; (c) 3.58 MHz output of the up convertor; (d) control-track signal.
6. Loss of 4.27 MHz drive to the up convertor in playback results in: (a) excessive hue error in the playback picture; (b) no color; (c) color out of lock; (d) color noise.
7. The comb filter uses a delay line that provides a delay of: (a) 0.5 μs; (b) 140 μs; (c) one field; (d) 63.5 μs.
8. The modulation system used for either modulator in an NTSC encoder is: (a) FM; (b) PM; (c) suppressed carrier AM; (d) single-sideband AM.
9. The maximum-obtainable chroma bandwidth available in the NTSC system is: (a) 600 kHz; (b) 1.2 MHz; (c) 3.58 MHz; (d) 4.2 MYz.
10. The factor 75% in the standard color-bar display refers to: (a) the degree of saturation; (b) the amplitude of the white bar in the top part of the display only; (c) the amplitude of the lower white bar in the display; (d) the amplitude of RGB signals that are applied to the encoder.

11. The correct Y/C ratio is noted in the composite 75% color bar waveform when: (a) burst is half sync amplitude; (b) the red and cyan bars are at maximum amplitude; (c) the yellow bar is the same height as the 75% white bar; (d) the yellow and cyan bars reach the same height as the 100% white bar.
12. The composite video signal with chroma remaining as side bands of the 3.58 MHz subcarrier is applied to the FM luminance modulator in: (a) color-under machines; (b) the Betamax; (c) VTRs intended for broadcast operations; (d) U-matics.
13. The ACC system in the color playback processor of two-head color under machines is especially designed to eliminate: (a) chroma noise; (b) chroma beat; (c) chroma flicker; (d) the effects of mistracking.
14. Time-base error produces random hue errors in the picture because: (a) burst and chroma are subject to opposite jitter effects; (b) the AFPC system in the receiver or monitor cannot follow instantaneous changes in burst chroma phase; (c) the FM system is particularly phase sensitive; (d) burst and chroma are separated in the recording process.
15. The 180° phase difference between subcarrier signals on alternate lines in the same field is due to: (a) the frequency relation between the subcarrier and horizontal-line rates; (b) a phase invertor that is driven at the H-line rate; (c) the odd number of lines in the raster; (d) the frequency relation between video and sound carriers.
16. When the camera is scanning a 50% gray area the subcarrier output of the camera is: (a) zero; (b) ½ the normal value; (c) 50 IRE units; (d) 42.5 IRE units.
17. In the standard 1 V(p-p) video signal produced by the VTR the amplitude of sync is approximately: (a) 0.4 volts; (b) 0.3 volts; (c) 0.2 volts; (d) 0.7 volts.
18. A reduction in chroma bandwidth that cuts equally into both sidebands results in an increase in: (a) chroma delay; (b) hue error; (c) saturation in large areas of the picture; (d) chroma noise.
19. In color-under machines, multiple generations result in an increase in color nosie and: (a) a decrease in chroma delay; (b) loss of color lock; (c) a decrease in chroma resolution; (d) a decrease in color saturation.
20. The color bar with the lowest Y value is: (a) yellow; (b) magenta; (c) blue; (d) green.

Answers:

1. (a)	6. (b)	11. (d)	16. (a)
2. (b)	7. (d)	12. (c)	17. (b)
3. (d)	8. (c)	13. (c)	18. (a)
4. (c)	9. (b)	14. (b)	19. (c)
5. (b)	10. (d)	15. (a)	20. (c)

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